Indian Head Division
Naval Surface Warfare Center
Indian Head, MD 20640-5035

IHTR 1863
29 February 1996

GET THE LEAD OUT

Susan T. Peters

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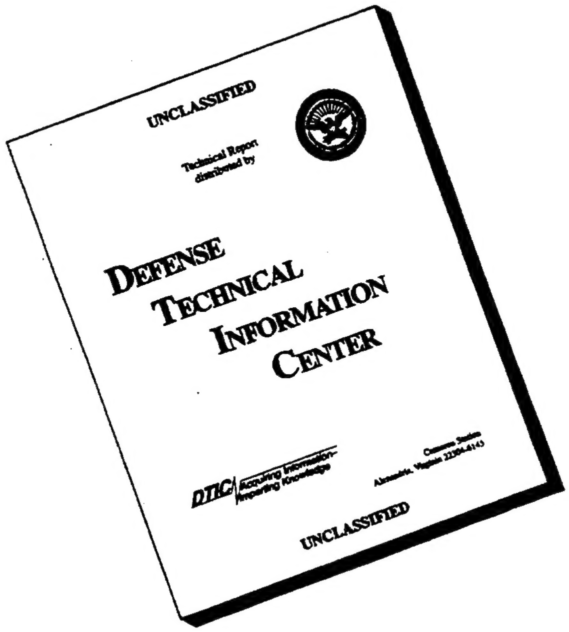

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In the interests of environmental responsibility, the Navy is seeking replacements for lead decoppering agents. These agents are necessary to remove the copper deposited on the barrel surface of a gun firing copper-banded projectiles. A brief review of the theory of decoppering will be presented to provide the rationale for our choice of bismuth as the replacement for lead.

Our test program was being conducted in the 5"/54 gun because the problem of lead toxicity poses two problems in this system: not only the environmental discharge during firings, but the propellant, Naco, contains a lead salt, rather than using lead foil. Protection of the workers manufacturing Naco from the lead salt incurs significant additional expense.

Naco was made without lead, fired in a pair of barrels in an attempt to copper the barrels. Though 156 rounds were fired from each barrel, neither showed any measurable coppering. One barrel did show moderate amounts of copper in bore-search examination. After a single round of either a charge loaded with 5 g of bismuth/tin foil or the standard Naco, the barrels were completely cleaned of copper.

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Coppering, Ballistic Testing, Decoppering, Lead

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FOREWORD

The work reported herein was performed at the Indian Head Division, Naval Surface Warfare Center, Indian Head, MD as part of our role as design agent for Navy gun propelling charges. The sponsor, Mr. Larry Massa, Code PM413 of the Crane Division, Naval Surface Warfare Center, funded the work through Product Improvement Program 93AC03.

Approved by:

T. Craig Smith
Manager, Gun Systems Branch

Released by:

William Yeckley
Director, Surface Weapons Division

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FIGURES

ACKNOWLEDGEMENTS

The author would like to thank Mssrs. Jim Rutkowski and Sid Bernstein of the US Army Armaments Research, Development and Engineering Center for their help in understanding the coppering problem and the Army's approach to that problem in artillery. Also, Mr. Paul Conroy of the US Army Research Laboratory was most helpful in elucidating the nature of the ballistic results.

INTRODUCTION

Objective:

The objective of the work presented here was to eliminate the lead carbonate from Naco propellant while still preventing copper from building up on the 5-inch, 54-caliber gun barrel. Any replacement decoppering agent should not only be effective, but also affordable and non-toxic. A method for the efficient introduction of the replacement decoppering agent into the propelling charge was also required.

Background:

Bullets whose rotating bands are made of copper or gilding metal leave a trace of copper in the gun barrel. Over time, this copper can accumulate to the point where ballistics are affected. Extreme cases can even lead to gun stoppages. Sometime in the past, lead was found to be effective in removing excess copper from the barrel. In most charges, lead foil is added to the charge, but Naco propellant contains a lead salt, basic lead carbonate, added to the formulation to perform the decoppering. Both systems have proven effective in preventing copper buildup.

With the recent emphasis on worker safety, Radford Army Ammunition Plant determined that properly protecting workers during the production of Naco involved their using specialized equipment to prevent exposure to the lead salt. Concerns were expressed that the increased cost associated with the use of the specialized protective equipment would drive up the cost of Naco propellant. Furthermore, we felt that it was likely that the use of lead in gun propelling charges would be challenged on a more general environmental basis. A biologically benign replacement for lead was needed.

A search of the literature led to Robertson's report of 1975 on the decoppering of gun tubes by lead[1]. In it he proposes that lead removes copper in gun barrels by dissolving the copper on the bore, forming a low-melting solution which is swept out of the barrel by the next round. He supports this mechanism by reference to the properties of lead, the phase diagram for lead and copper, and the phase diagram for lead and iron. An older theory of decoppering holds that lead removes copper by forming a brittle alloy which is mechanically removed by the succeeding round. Robertson's examination of the phase diagrams shows this is highly unlikely as the copper would have to exist in the molten state to form the alloy.

After demonstrating the soundness of his proposed mechanism, he examined other low-melting metals for their fit into the decoppering scheme. Only bismuth is noted as having the potential to exceed the decoppering action of lead. (It is interesting to note that Robertson declares tin to be a poor candidate for a

[1] Robertson, Wayne, "Decoppering of Gun Tubes by Lead," AC-TR-75-002, Picatinny Arsenal, August 1975.

decoppering agent because it forms a solid alloy with copper.) The Army has been evaluating tin as an alternative to lead for decoppering; the results achieved may help determine which theory is better.

Another issue of relevance to decoppering is the placement of the agent in the propelling charge. Robertson makes a strong argument for placing the agent near the wall of the chamber, that is, *around* the charge. This should keep the agent in the boundary layer of gas next to the coppered barrel wall. Canadian experience with lead foil crumpled into a ball and placed on top of the charge versus formed into a loose "donut" [sic] showed a dramatic difference in the degree of decoppering with the ring being much better than the ball[2].

To keep the charge assembly process simple, the agent can be included as a salt in the propellant formulation as has been done with Naco. The formulation for Naco is given below:

Ingredient	Weight %
Nitrocellulose (12% nitrogen)	93.55
Butyl stearate	3.00
Ethyl centralite	1.20
Basic lead carbonate	1.00
Potassium sulfate	2.00

A standard Naco charge for the 5-inch, 54-caliber gun is about 20.36 lb (9.24 kg) of which 72 g are atomic lead. From Robertson's analysis, we see that a saturated solution of copper in lead contains 6.7% copper. Since the current charge is effective in preventing coppering of the bore, the most copper that can be removed by the 72 g of lead in a single round is 5 g. This is the amount of copper that we will assume needs to be removed. The details of the calculation are given in Appendix A.

[2]Canadian Defence Research Board letter to US Bureau of Ordnance of 2 May 1955.

APPROACH

To find a safe, effective replacement for lead, we pursued the suggestions of Robertson. We examined the material safety data sheets of bismuth and a number of its salts which would be expected in combustion with propellant. These compounds all proved to be rather benign, even used in medications and cosmetics! The biologically safe criterion seemed to have been met.

In trying to locate a source of bismuth, we learned that the pure metal is too brittle to form into a foil. A foil is desirable because it should melt more quickly during a gun firing. In the past, loosely crumpled lead foil balls have sometimes been found to have formed into tightly packed balls after rough handling. When tightly packed, some solid lead had been found after firings, indicating that not all the lead had been available for decoppering. To make bismuth malleable enough to form a foil, it must be alloyed with another metal. Among those which are effective is tin. Tin was noted in Robertson's report as being neither effective nor detrimental to the decoppering action of lead. The bismuth-tin alloy is also very low melting, an important property for decoppering. Furthermore, a check of the toxicity of tin and its salts showed it to be relatively nontoxic. The alloy of interest is 58% bismuth and 42% tin. It is available in a 1-in (25.4-mm) wide by 0.002-in (0.051-mm) thick ribbon.

Because copper is barely soluble in tin, we attributed no decoppering action to it. Bismuth forms a saturated solution with copper which is equal parts of each metal. Thus, to remove the 5 g of copper expected on the barrel, we would need 5 g of bismuth or approximately 9 g of the alloy. Given the dimensions of the 5-in cartridge-case and the ribbon, twice around the interior circumference of the case near the mouth would yield 9 g of the bismuth-tin alloy. We chose to glue the ribbon to the interior of the case to keep it in the boundary layer.

To assess the decoppering action of the bismuth, we needed to copper a barrel. To do this, we had a lot of Naco propellant made without the lead carbonate. After a number of shots with this propellant, copper would build up on the barrel, and we could test our replacement decoppering agent. In a broad sense, our test program was to copper a barrel, decopper it with standard leaded rounds, copper it again, and then decopper it with the replacement decoppering agent. Counting the number of rounds necessary to remove the copper would provide a measure of the efficiency of each method. The criterion for considering a barrel coppered was selected to be a 0.008-in (0.203-mm) reduction in the bore diameter as determined by star-gauging. This value was adopted from the Army where a similar program for artillery is on-going. Their experience was that about 80 to 100 rounds would be needed to achieve this level of coppering.

Tony Boczon, the test engineer at the Dahlgren Division, Naval Surface Warfare Center, developed a rather elegant test plan that incorporated firing two barrels side-by-side. This minimized downtime for barrel cooling prior to star-gauging. Twenty unleaded rounds would be fired in each cleaned and inspected barrel, followed by star-gauging after overnight cooling. Twenty more rounds would be fired from each barrel, again followed by cooling and star-gauging. Based upon the star-gauge data, the rates of coppering for each barrel would be determined and then the number of rounds to yield the desired bore reduction calculated for each barrel. The predicted numbers of rounds would then be fired in each barrel and the cooled barrels star-gauged.

Any necessary additional rounds needed to completely copper the barrels would then be fired and the bores rechecked. At this point, different testing would begin in the two guns. The first would fire standard, leaded Naco, and the second would fire rounds with the bismuth-tin ribbon. Only one shot per day would be fired for the decoppering series, with star-gauging being done after each shot. Firing would continue until the barrels were returned to their original clean state. A second, single-gun series would be fired with another amount of bismuth-tin loaded into the charges to allow determination of a more optimal decoppering agent level.

RESULTS

Radford produced a 7,290-lb (3,307-kg) lot of Naco without the lead carbonate, RAD94D-QI5348. (The propellant description sheet may be found as Appendix B.) We requested the standard granulation since the amount of lead carbonate in the formulation is small and we had no way of predicting the burning rate effects of eliminating the lead carbonate. Some slight manufacturing difficulties were noted, but they were not necessarily due to the elimination of the lead. As a result of adding too much solvent, drying was affected, and the surface of the grains showed small cracks, though these were not noticeable to nonproduction personnel. This difficulty was evidenced in the lot's failing to meet the specification for outer diameter uniformity. The measurements of the grains performed at the Indian Head Division indicated that after measurements were made at Radford, further drying and shrinkage occurred. As would be expected with elimination of the densest ingredient, the finished propellant was less dense than the specification. Relative quickness and relative force were 99.4 and 100.6, which are within specification limits. The charge-weight probe firings yielded a charge weight of 20.52 lb (9.308 kg).

Samples of the lead-free Naco were shipped to Indian Head for characterization testing to include sensitivity, burning rate, and compatibility with the bismuth-tin alloy. The bulk of the lot was shipped to Dahlgren for ballistic testing. The compatibility of the bismuth-tin alloy and the lead-free Naco was demonstrated with differential-scanning calorimetry (Appendix C). The cardgap test yielded three negative results at zero cards. Impact sensitivity was measured with the Bruceton method to be 220 mm with a 5-kg weight. Both sliding friction and electrostatic discharge sensitivities were lower than the limits the machine could measure. These test data sheets are included as Appendix D.

The ballistic testing performed at Dahlgren to copper the barrels went much more slowly than expected. After 25 rounds were fired in each barrel in late August 1994, no change was seen in barrel dimensions. Another 50 or so rounds were fired, again without any coppering apparent from star-gauge measurements. One of the barrels was fired for a total of 156 rounds then measured again, showing a four thousandths bore restriction, only half of our coppering criterion. At this point we were faced with a difficult decision. Our supply of unleaded Naco was more than half gone with one barrel only half coppered. Should we continue firing in the half-coppered barrel, probably running out of lead-free Naco and, so, having no standard against which to compare the bismuth-tin alloy? We chose to declare the barrel with the four thousandths restriction as coppered and fire the other barrel to the same number of shots. After firing these shots and expending most of the lead-free propellant, both barrels were bore-searched, revealing light copper deposits in one barrel, 16991, and heavier deposits in the other, 16972. The copper was deposited about 35 inches downbore from the case mouth. Several months after these postfiring star-gaugings and bore-searches, it was determined that there was a problem with the star-gauge head. Remeasurement of the barrels showed no significant change in the dimensions of the bore from those taken prior to the firings. Bore-search inspection did show that one of the barrels had significant amounts of green material (presumed to be copper oxide) and small spots of rust on the bore surface. The other barrel had greater rust formation but very little copper. Copies of the star-gauge and bore-search reports make up Appendix E. Given their identical histories, we have no explanation for this variation, though barrel-to-barrel variability in susceptibility to coppering was recognized during World War II when guidance on decoppering was provided to the fleet. In a publication for the fleet, the Bureau of

Ordnance, seeking input on the coppering conditions in large guns which would allow the phenomenon to be understood, stated that "The degree of coppering from gun to gun in larger calibers is such that the use of a fixed amount of foil for each caliber may become unreliable, and therefore, its use ... is left to the discretion of the fleet."[3] Though hard to explain, the variation in coppering between our two barrels had good precedent.

At this point we had two barrels, each of which had had 156 unleaded rounds fired through it, neither of which had any measurable bore restriction, and only one of which had significant visible copper deposits. How were we to determine if the new decoppering agent worked? What would be our measure of cleanliness? The symptom of a coppering problem in a gun is changes in initial velocity and, in extreme cases, difficulty in chambering a round. Since our situation was one of only minor coppering, perhaps variations in velocity could be an indicator for coppering. Velocity versus shot number was plotted for each barrel and a straight line fitted to the data (Figures 1 and 2). That line rose slightly for each barrel, but when the data were examined more closely, it was found that when separated by date of firing (Figures 3 and 4), the data for those days on which 20 or so shots were fired gave scattered results. It was the rise of the velocity on the last day of firing, in which over 70 shots were fired, that accounted for most of the rise of the line. This rise of velocity during extended periods of firing is recognized (though not explained) for metal-banded projectiles and is not a good measure of the coppering of the barrel[4]. With no quantifiable measure of coppering, we resigned ourselves to using the bore-search images to determine whether a barrel was coppered.

It was now time to assess the relative decoppering action of the bismuth-tin alloy against the standard Naco lead carbonate. Our very conservative calculation of the amount of bismuth needed to equal the decoppering action of the lead contained in a standard Naco charge had shown that two strips of the foil inside the case would be more than adequate. Since we used so much of our lead-free Naco in coppering the barrels, we would not have the luxury of doing two firing series to determine the optimal level of bismuth-tin. We decided to gamble on a single strip of foil, reasoning that so much more of this material would come in contact with the wall compared to the lead which is evenly distributed across the bore that it would work more efficiently. Our firing sequence would be to fire a single shot with the bismuth-tin foil, bore-search, then fire another shot until the barrel appeared clean. Once the barrel was seen to be clean, a series of shots of the test powder versus the master powder would be done to examine the effect on velocity that the cleaning had made. This process would be done on barrel 16972, the more heavily coppered barrel, with the bismuth-tin rounds, while depot-loaded rounds would be used on barrel 16991.

Barrel 16972 was completely clean after a single shot. The succeeding shots comparing master powder to the test rounds yielded identical average velocities of 2,699 ft/s. Figures 1 and 2 show that this velocity compares favorably with that at which the barrel was shooting prior to the coppering series. We took this as an additional indication that the barrel had been returned to its original condition. Barrel 16991 also showed complete cleaning after a single round of regular Naco. Unfortunately, the master powder and the depot-loaded rounds yielded differing average velocities, 2,691 and 2,677 ft/s respectively. In a test efficiency move, a projectile test was added to this velocity comparison series, meaning that each type of round fired a different projectile. Thus the cause of the velocity difference between the rounds is unclear.

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[3] Bureau of Ordnance Circular Letter A11-47 dated 7 July 1947.

[4] Clarke, Emerson, "Summary of Firings to Determine Influence of Rotating Band Material on Muzzle Velocity of 105-mm Howitzer," BRL MR 2137, US Army Ballistic Research Laboratory, dated November 1971.

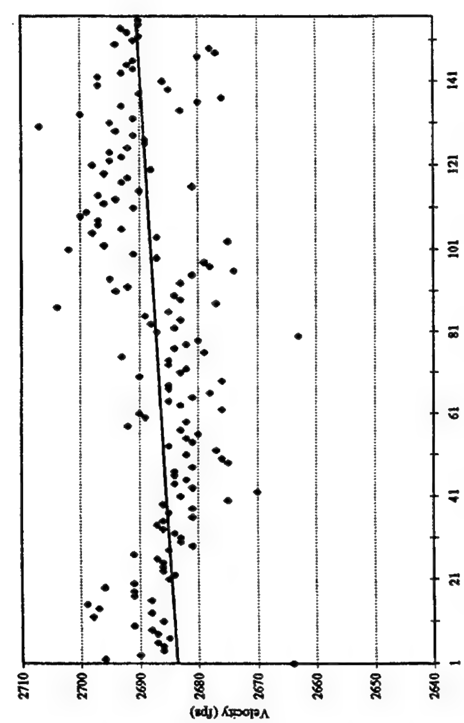


Figure 1. Velocity Variation Over Time for Barrel 16972

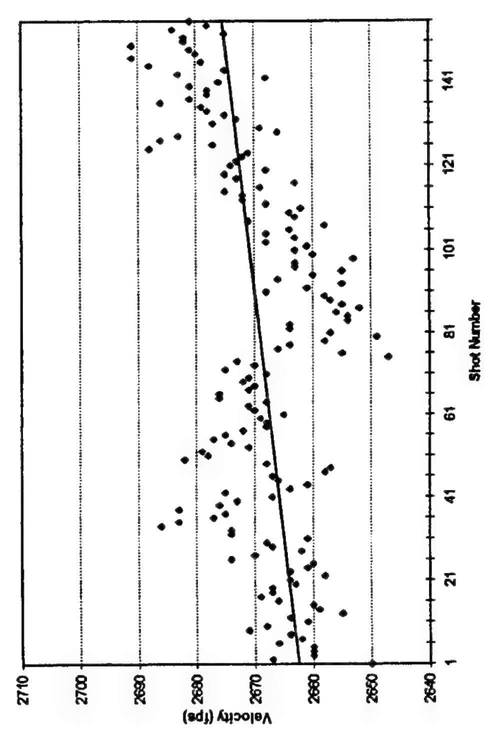


Figure 2. Velocity Variation Over Time for Barrel 16991

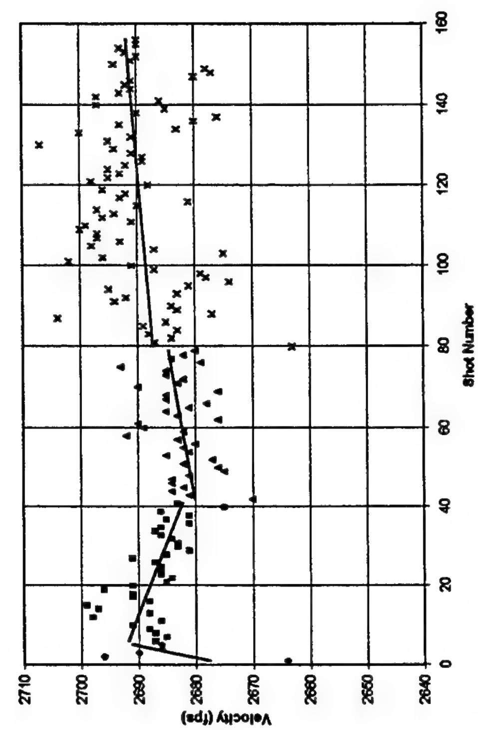


Figure 3. Velocity Variation by Firing Date for Barrel 16972

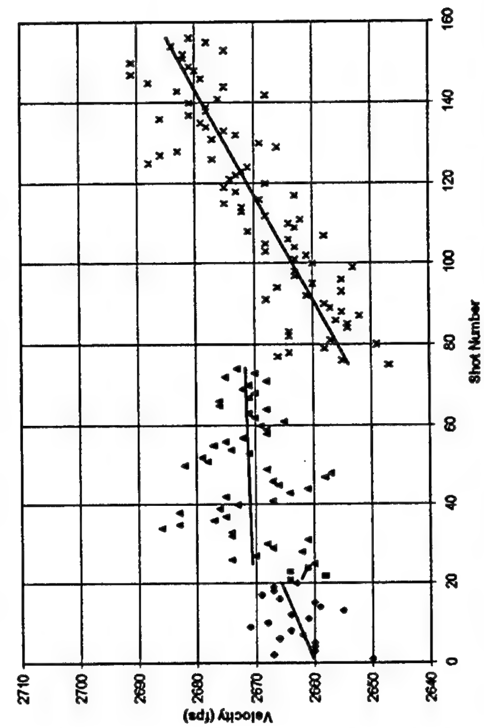


Figure 4. Velocity Variation by Firing Date for Barrel 16991

DISCUSSION AND CONCLUSIONS

The historical experience with variability of coppering in major caliber barrels was confirmed in these tests. Given the location of the copper at a downbore location and the apparently insignificant effect on muzzle velocity, there may actually be no coppering problem in the 5-inch, 54-caliber gun system. Our test program was too limited to make that call at this time so we will continue to recommend the use of a decoppering agent in charges for this system.

Based upon the cleaning of a moderately coppered barrel with a single round using 5 g of bismuth-tin foil, we are very comfortable in recommending such a charge for maintenance of a barrel in a copper-free state. It is likely that an even lower level of this decoppering agent would suffice, but the costs of a test program to demonstrate this are unwarranted. Our research into the toxicity of bismuth and tin show both the elements and their oxides (which could be formed in the gun) to be biologically benign. Addition of the foil component to the charge configuration will certainly impact the loading operation, though it should not pose insurmountable problems. To prevent any problems with propellant grains sticking together from the adhesive used to affix the foil to the case, the foil should probably be mounted to the cases in a separate operation prior to the main loading operation. In future rounds, bismuth powder could be suspended in a suitable medium and sprayed on the inside of the case.

Appendix A

COPPER CALCULATION

From Robertson's report we found that saturated solutions of copper (Cu) in metals contain these fractions of Cu:

Metal	Fraction Cu
Lead (Pb)	0.067
Bismuth (Bi)	0.5
Tin (Sn)	0.006

The amount of atomic lead in a standard Naco charge is calculated as follows:

20.4 lb Naco/chg × 454g/lb × 0.01 g $PbCO^3$/g Naco × 207/ (207 + 12 + 48) g Pb/g $PbCO^3$

= 72 g Pb/chg

Determining how much Cu is dissolved in the 72 g of lead from a single charge:

72 g Pb = g Pb/g Pb:Cu soln × g Pb:Cu soln

72g/(1 - 0.067) g Pb/g Pb:Cu soln = g soln

77g = g of soln

g Cu in soln = g soln - g Pb

g Cu in soln = 77 - 72 g

5 g = Cu in soln

Thus 72 g of lead dissolve only 5 g of copper. We will assume that removal of 5 g of copper per charge is adequate to prevent coppering.

A Bi/Cu solution is 50 parts bismuth and 50 parts copper. Thus removal of the 5 g of copper should require only 5 g of bismuth.

Our foil is 58 parts Bi and 42 parts Sn. The tabulation above shows that tin should dissolve very little copper, therefore we will assume no decoppering ability is contributed by the tin. Rounding up, we see that we will need 9 g of foil to achieve the same level of decoppering as provided by the lead carbonate in the Naco.

The foil is 1 in wide by 0.002 in thick and has a density of 8.56 g/cm^3. Calculating 9 g of foil and rounding, we see that we need about 32 in of foil to make 9 g. Given the inside dimension of the case near the mouth as 5.25 in, we see that two strips around the circumference inside the case should provide the required amount of foil. To ensure maximum melting, the strips should not be on top of one another. The top of the upper strip should be about 1 in below the top of the propellant bed to avoid interference with wad.

Appendix B

PROPELLANT DESCRIPTION SHEET

PROPELLANT DESCRIPTION SHEET

REPORTS CONTROL SYMBOL
EXEMPT-PARA-7-2a
AR 335-15

IHTR 1863

COMPOSITION BS-NACO, TYPE I, COMPOSITION D FOR 5-INCH, 54 CALIBER	DA LOT NUMBER RAD94D-QI5348
SPECIFICATION WS 16619D, 6 OCT 87 and ADL3188989H dtd 16 MAR 92	PACKED AMOUNT 7,290 POUNDS
MFG. AT RADFORD ARMY AMMUNITION PLANT, RADFORD, VA	CONTRACT NUMBER DAAA09-91-Z-0001 / CLIN NUMBER 4018AE / PRON NUMBER F1A0DBQM1FK

NITROCELLULOSE

ACCEPTED BLEND NUMBERS	NITROGEN CONTENT	KI STARCH (65.5 °C)	STABILITY (134.5 °C)
W51,939Y	MAX 12.07 %	45+ MIN	30 MIN
	MIN 12.07 %	45+ MIN	30 MIN
	AVG. 12.07 %	45+ MIN	30 MIN
Y-DESIGNATES WOOD SULFITE CELLULOSE			EXPLOSION HR.

MANUFACTURE OF SOLVENT PROPELLANT

0.82 POUNDS OF SOLVENT PER POUND NC/DRY WEIGHT INGREDIENTS CONSISTING OF 72 POUNDS OF ALCOHOL AND 28 POUNDS ETHER PER 100 POUNDS SOLVENT PERCENTAGE REMIX TO WHOLE 10

PROCESS-SOLVENT RECOVERY AND DRYING

TEMPERATURES °C FROM	TO	PROCESS	DAYS	HOURS
	21	LOAD SOLVENT RECOVERY TANK		
	21	HOLD SOLVENT RECOVERY TEMPERATURE		104
21	35	INCREASE SOLVENT RECOVERY TEMPERATURE		6
	35	HOLD SOLVENT RECOVERY TEMPERATURE		8
	64	WATER DRY CYCLE		192
	63	AIR DRY CYCLE		12 - 18

Appendix D

SENSITIVITY DATA

TESTS OF FINISHED PROPELLANT

PROPELLANT COMPOSITION CONSTITUENT	PERCENT FORMULA	PERCENT TOLERANCE	PERCENT MEASURED	STABILITY AND PHYSICAL TESTS	FORMULA	ACTUAL
				HEAT TEST 134.5°C		
NITROCELLULOSE	93.55	NOM.	94.35	NO EXPLOSION	5 HRS. MIN.	
n-BUTYL STEARATE	3.00	± 0.30	3.27	FORM OF PROPELLANT		CYLD.
ETHYL CENTRALITE	1.20	± 0.20	1.32	NO. OF PERFORATIONS		7
POTASSIUM SULFATE	1.25	± 0.30	1.06			
TOTAL	100.00		100.00	COMPRESSIBILITY, %	30 - 60	52
TOTAL VOLATILES	5.0	MAX.	2.15			
MOISTURE	2.00	± 1.00	1.32	LOADING DENSITY,		
GRAPHITE GLAZE	0.10	± 0.05	0.09	gm/cc	0.850 min.	0.849

*COMPUTED ON A TV AND GRAPHITE FREE BASIS

CLOSED BOMB

TEST	LOT NUMBER	TEMP °F	RELATIVE QUICKNESS	RELATIVE FORCE
	RAD94D-QI5348	+90	99.4	100.6
STANDARD	RAD-RHBF-67358	+90	100%	100%

REMARKS

FIRED IN A NOMINAL SIZE 200cc CLOSED BOMB.

RQ MUST BE ± 3.0 PERCENT OF STANDARD.

PROPELLANT DIMENSIONS (inches)

	SPECIFICATION	DIE	FINISHED	STD.DEV.IN% OF MEAN DIMENSIONS SPEC.	ACTUAL
LENGTH(L)		0.720	0.6108	6.25 MAX	1.76
DIAMETER(D).		0.417	0.2687	3.125 MAX	4.12
PERF.DIA.(d)		0.031	0.0248		
WEB					
INNER		0.083	0.0470		
OUTER		0.077	0.0499		
AVERAGE		0.081	0.0484		
AVG. % WEB DIFF.	15 MAX.		6		
AVG. L:D	2.10 - 2.50		2.27		
D:d	5.0 - 15.0		10.8		

DATES
PACKED 4/15/94
SAMPLED 4/15/94
TEST FINISHED 4/28/94
OFFERED 5/02/94
DESCRIPTION SHEETS FORWARDED 5/3/94

TYPE OF PACKING CONTAINER M2 & MK7 METAL CONTAINERS 66 AT 110 LBS. NET (30 LBS. SAMPLES) = 7,290 LBS.

REMARKS

THIS LOT FAILED TO MEET THE OUTSIDE DIAMETER UNIFORMITY AND THE SCREEN LOADING DENSITY OF THE APPLICABLE SPECIFICATION. ALL OTHER REQUIREMENTS WERE MET.

THIS LOT DOES NOT MEET ALL CHEMICAL & PHYSICAL REQUIREMENTS OF THE APPLICABLE SPECIFICATION.

SIGNATURE OF CONTRACTOR'S REPRESENTATIVE	SIGNATURE OF GOVERMENT QUALITY ASSURANCE REPRESENTATIVE
R. E. HEDRICK R E Hedrick	Larry D. Hoyt 5/3/94

ARRCOM FORM 214R 10 AUG 77

Appendix C

COMPATIBILITY DATA

8000
Ser 3330M/219/dg
19 Jul 94

MEMORANDUM

From: 3330M
To: 6210C (Susan T. Peters)
Via: 3330 *STG*

Subj: DSC COMPATIBILITY TESTING OF EXPERIMENTAL NACO PROPELLANT WITH BISMUTH/TIN ALLOY

Ref: (a) Lab reference #915916, 918665
(b) Chemical Compatibility Determination Using Thermal Analysis, Memo/8000 Ser 3330/20 of 26 Oct 92, A Proposed Method

Encl: (1) Table I of Reference (b)
(2) - (6) Results of DSC Testing

Summary: Experimental NACO propellant RAD-94D-Q15348 was deemed compatible with the bismuth/tin alloy.

* * * *

1. A dynamic Differential Scanning Calorimetry (DSC) study was conducted to examine the compatibility of experimental NACO gun propellant (i.e., without the basic lead carbonate ordinarily added) with a bismuth/tin alloy. In this study, samples were placed in open aluminum sample pans and heated at a rate of 2°C/min from 30°C to 300°C while subjected to a nitrogen purge. The propellant was examined by itself and in contact with the alloy. The average peak temperature of the first energetic exotherm of the propellant was then determined. The result of DSC testing can be seen in enclosures (2) thru (6).

2. The initial step in compatibility testing by DSC is to examine the decomposition profile of the energetic and to determine the peak temperature of the energetic exotherm. The energetic is then combined with each of the contact materials to be examined in the study and the peak temperature of the energetic is once again determined. A shift in this peak temperature would indicate that by combining the energetic with the contact material, the decomposition of the energetic had been accelerated. Any combination that lowers the peak temperature of the energetic exotherm has a degree of incompatibility. The greater the shift, the greater the degree of incompatibility of the combination.

3. The average peak temperature of the first energetic exotherm when examined by itself was determined to be 191.43°C. When bismuth/tin alloy was added to the energetic and heated, the average peak temperature of the first energetic exotherm increased 0.39°C to 191.82°C. This, by definition, means that the experimental NACO propellant examined in this study is deemed compatible with the

Subj: DSC COMPATIBILITY TESTING OF EXPERIMENTAL NACO PROPELLANT WITH BISMUTH/TIN ALLOY

bismuth/tin alloy.

4. If you have any questions or need additional information, please feel free to contact me at extension 4759/1731.

Rob DeMarr

ROBERT S. DE MARR

TABLE 1
COMPATIBILITY GUIDELINES FOR ADMIXTURES BASED
ON DSC AND TG DATA

Degree of Incompatibility	DSC Peak max. °C Δ (mixture-ingredient)	TG[1] Δ (% mixtures-% ingredients)
None	0 - 4	0 - 4
Slight	5 - 9	5 - 9
Small	10 - 19	10-19
Moderate	20 - 29	20 - 29
Large	>30	>30

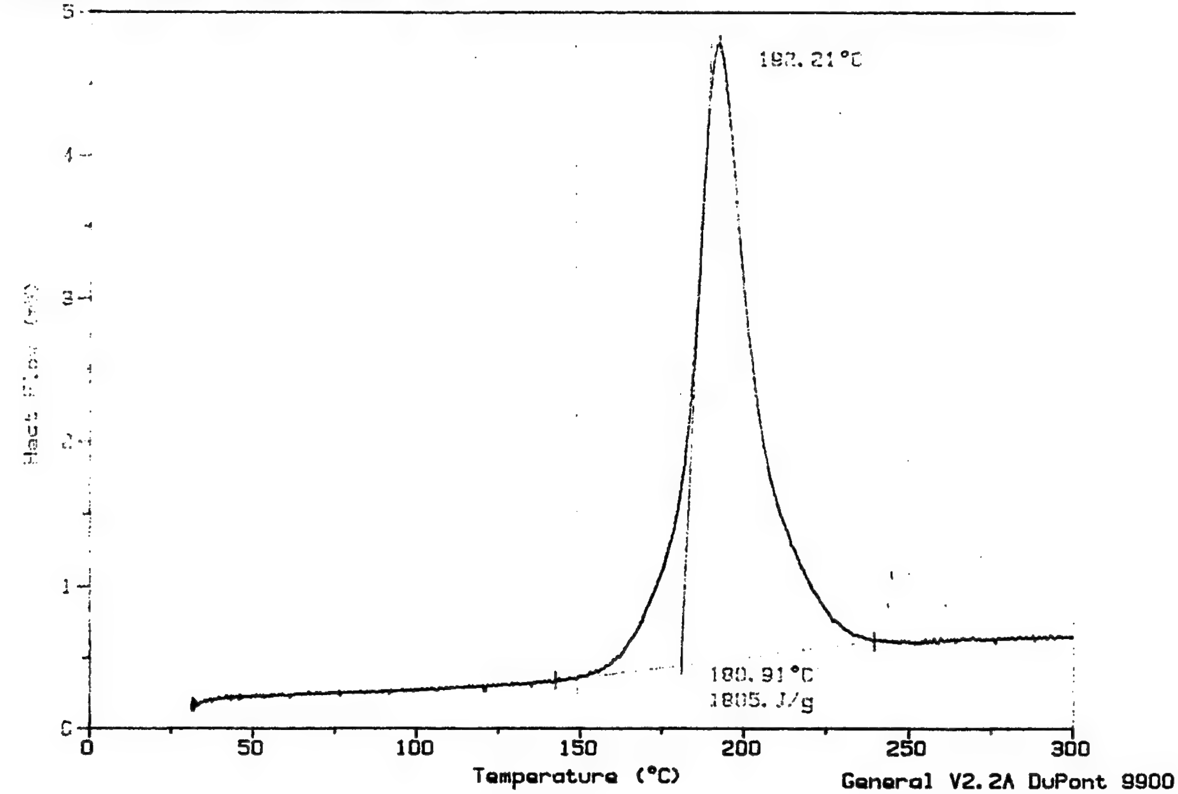
Reproduced from reference (b)

IHTR 1863

Sample: EXPERIMENTAL NACO
Size: 1.6000 mg
Method: 30°C TO 300°C AT 2°C/MIN
Comment: 250 ML/MIN N2 - OPEN PAN

DSC

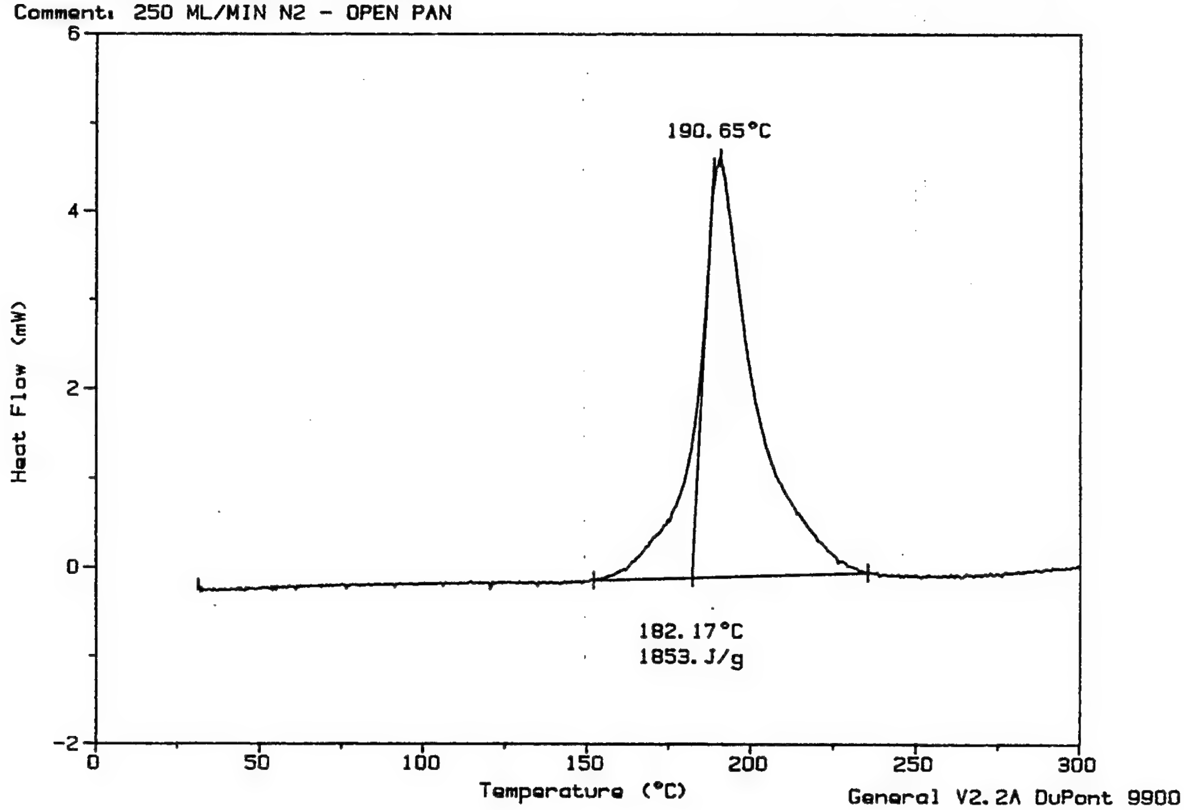
File: 918665.01
Operator: ROBERT DE MARR
Run Date: 14-Jul-94 13:20



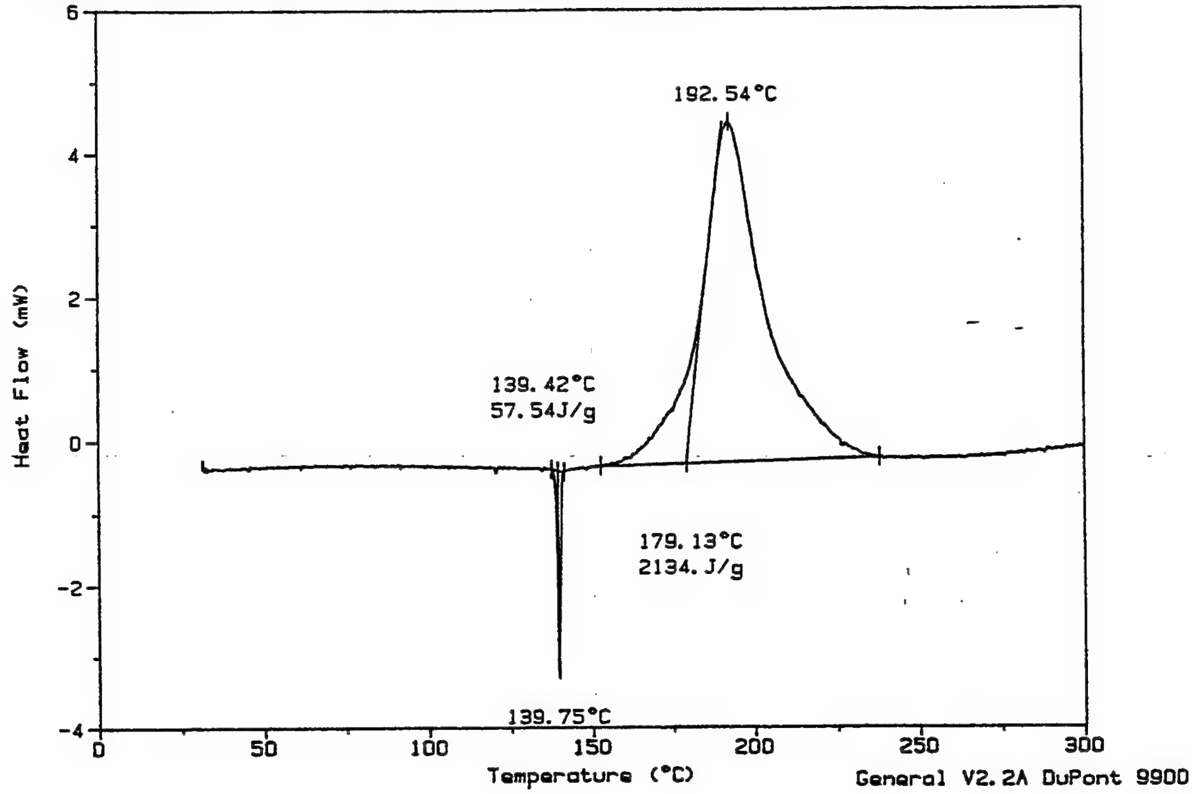
Sample: EXPERIMENTAL NACO
Size: 1.5400 mg
Method: 30°C TO 300°C AT 2°C/MIN
Comment: 250 ML/MIN N2 - OPEN PAN

DSC

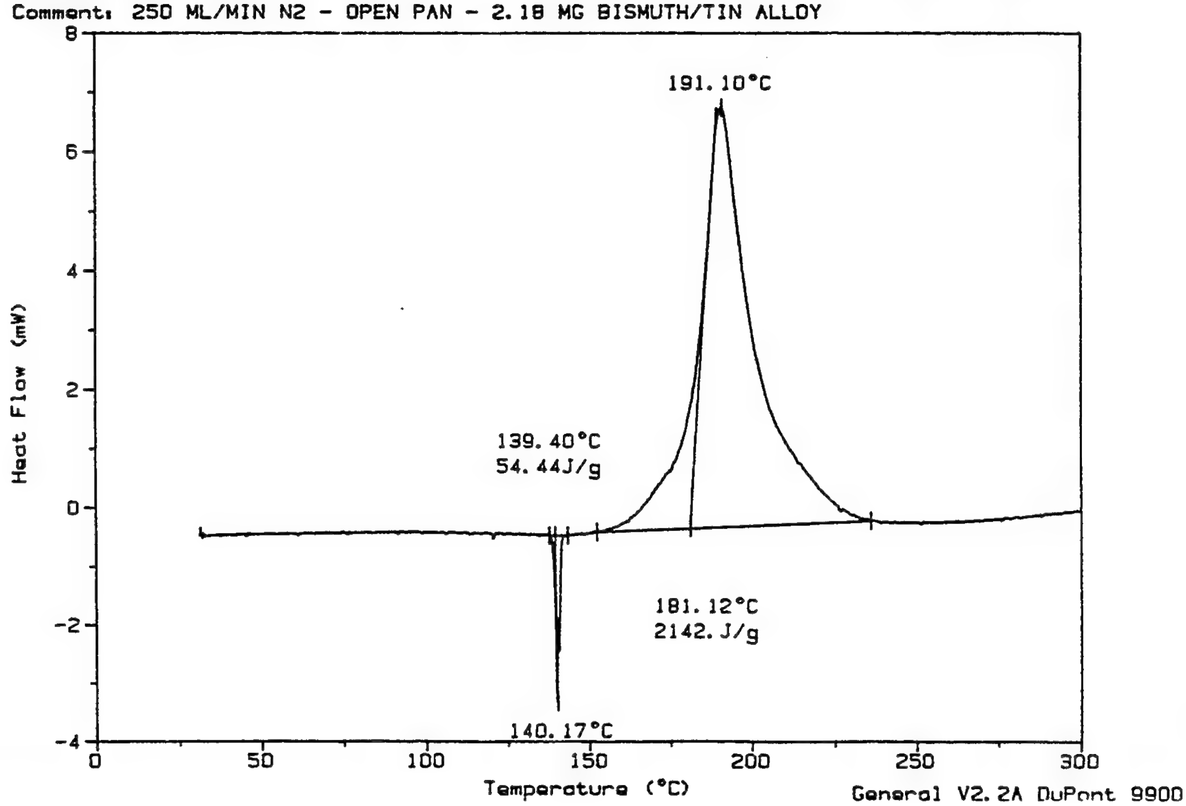
File: 918665.02
Operator: ROBERT DE MARR
Run Date: 15-Jul-94 07:52



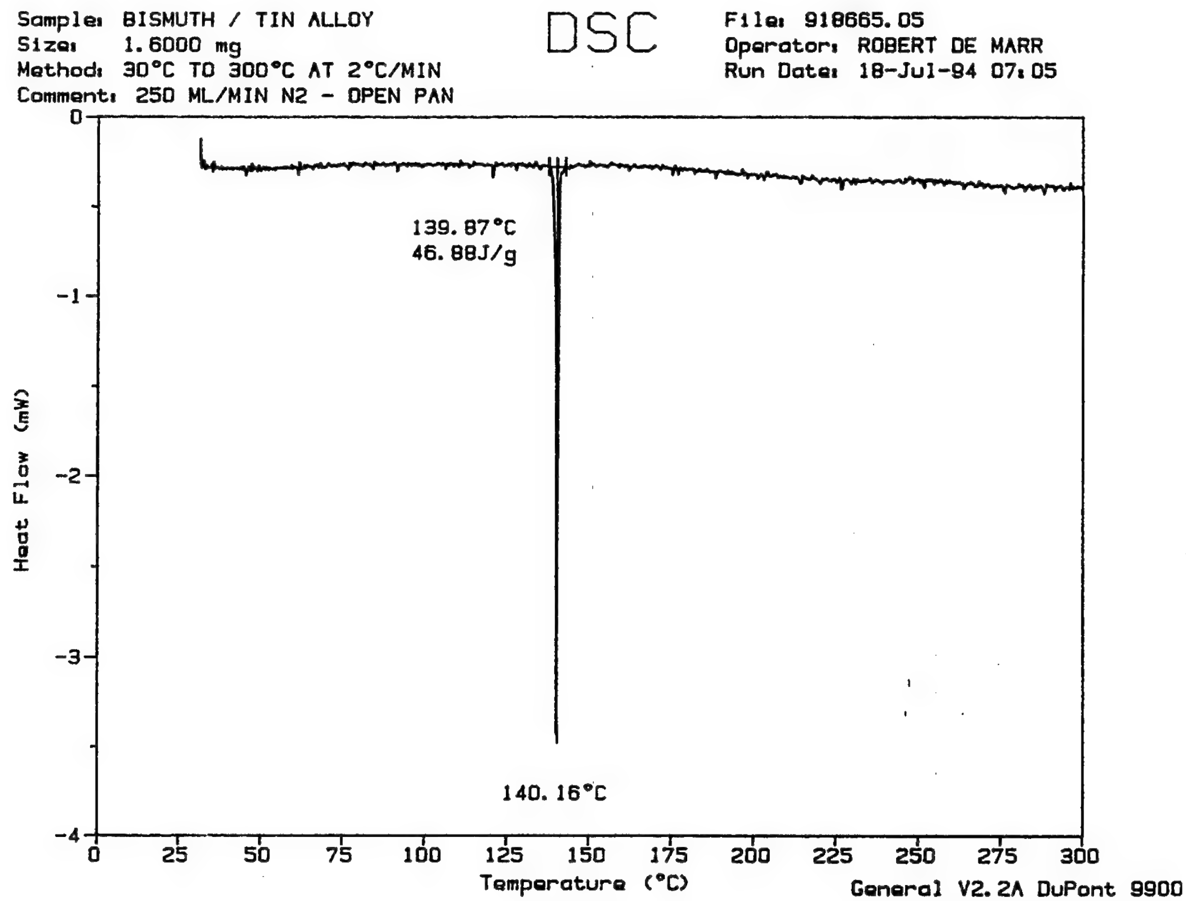
Sample: EXPERIMENTAL NACO + Bi/Sn ALLOY DSC File: 918665.03
Size: 1.5200 mg Operator: ROBERT DE MARR
Method: 30°C TO 300°C AT 2°C/MIN Run Date: 15-Jul-94 10:36
Comment: 250 ML/MIN N2 - OPEN PAN - 1.79 MG BISMUTH/TIN ALLOY



Sample: EXPERIMENTAL NACO + Bi/Sn ALLOY DSC File: 918665.04
Size: 2.0000 mg Operator: ROBERT DE MARR
Method: 30°C TO 300°C AT 2°C/MIN Run Date: 15-Jul-94 13:30
Comment: 250 ML/MIN N2 - OPEN PAN - 2.18 MG BISMUTH/TIN ALLOY



IHTR 1863



Sample: BISMUTH / TIN ALLOY
Size: 1.6000 mg
Method: 30°C TO 300°C AT 2°C/MIN
Comment: 250 ML/MIN N2 - OPEN PAN
DSC
File: 918665.05
Operator: ROBERT DE MARR
Run Date: 18-Jul-94 07:05
139.87°C
46.88J/g
140.16°C
Heat Flow (mW)
Temperature (°C)
0
-1
-2
-3
-4
0
25
50
75
100
125
150
175
200
225
250
275
300
General V2.2A DuPont 9900

Appendix D

SENSITIVITY DATA

27 July 1994

MEMORANDUM

From: 9120
To: 6210

Subj: SENSITIVITY TEST REPORT FOR NACO PROPELLANT

Ref: (a) Request by SUSAN PETERS, Code 6210C of 20 JULY 1994.

1. As requested by reference (a), the following information is forwarded:

SAMPLE NO.	IMPACT (MM) NPP3+ METHOD	IMPACT (MM) BRUCETON METHOD	SLIDING FRICTION (PSIG)	ELECTROSTATIC DISCHARGE (JOULES)
RAD 94D Q15348	300	220	>980	>8.33

2. If there are any questions, please call Tom Chesley, Code9120cc, or Phil Thomas, Code 9120 on X4109 or X6463.

Philip Thomas
PHILIP THOMAS

Copy to:
0412
9120
6210
Sensitivity Lab File

BRUCETON WORKSHEET

SAMPLE: EXPERIMENTAL NACO PROPELLANT NPP3+ = 300 mm test #:

height (mm)	log of height	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	i	ni	i(ni)	i^2(ni)
1000	2.0																										0	0	0	0
794	1.9																										0	0	0	0
631	1.8																										0	0	0	0
501	1.7																										0	0	0	0
398	1.6																										0	0	0	0
316	1.5	P		P										P													3	0	0	0
251	1.4		1		P		P		P		P		1		P		P		P								2	2	4	8
200	1.3					1		1		1		1				1		1		P		P		P		1	1	7	7	7
158	1.2																				1		1		1		0	3	0	0
126	1.1																										0	0	0	0
100	1.0																										0	0	0	0
79	0.9																										0	0	0	0
63	0.8																										0	0	0	0
50	0.7																										0	0	0	0
40	0.6																										0	0	0	0
32	0.5																										0	0	0	0
25	0.4																										0	0	0	0
20	0.3																										0	0	0	0
16	0.2																										0	0	0	0
13	0.1																										0	0	0	0
																											SUMS:	12	11	15
																												N	A	B

The lowest drop height with recorded data is assigned an "i" value of 0.
Each successively greater height is assigned values of 1, 2, 3, etc.

The following values are calculated:
n_i=number of no-fires at each log height
$N=\sum n_i$ (total no-fires at all hieghts)
$A=\sum i(n_i)$ (i value times # of no-fires at that height, totalled for all heights)
$B=\sum i^2(n_i)$ (i value squared times # of no-fires at that hgt., total for all hgts.)
C=log interval of lowest drop height

The 50% height if then calculated as follows:
$M=C+0.1(A/N+0.5)$
$H50=10^M$
$S=0.162[(NB-A^2)/N^2+0.0219]$

P = POSITIVE (fire)

1 = NEGATIVE (no-fire)

C= 1.20 M= 1.34 Log units

H50= 220 mm S= 0.07 Log units

Date: 20-Jul-94

Test operator: T. CHESLEY/D. REMMERS

Requestor: S. PETERS, 6210C

Temp.: 23 °C RH: 52 %

NSWC INDIAN HEAD DIVISION

2800
Ser 3220B6/95/fek
7 Jul 94

MEMORANDUM

From: 3220
To: 6210

Subj: CARD GAP TEST REPORT FOR NACO PROPELLANT

Ref: (a) Request by S. Peters, Code 6210C

1. As requested by reference (a), the following information is forwarded:

MIX NO.	SHOT NO.	EXPLOSIVE WT. (GRAMS)	NO. CARDS	RESULT
RAD 94D-Q15348	1	113	0	NEG
	2	109	0	NEG
	3	108	0	NEG

2. If there are any questions, please call Paul Wallman, Code 3220D2, Frank Kolstrom, Code 3220B6, or Gil Bivins, Code 3220C2, on X4542.

ROBERT H. RAST

Copy to:
0412
6210C
3220D2

APPENDIX E
BARREL DESCRIPTIONS

5"/54 No-Lead Propellant Test Stargauge Data

All measurements were on cold gun, with points up.

Distance (in.) from muz. face		16991 before cop. 7/25/79	16991 156 rds 12/5/94	Diam. Constric x1000	16972 before cop. 2/20/80	16972 156 rds 12/5/94	Diam. Constric x1000
232		5.268	5.268	0	5.267	5.268	-1
231		5.257	5.255	2	5.255	5.255	0
230		5.195	5.196	-1	5.195	5.194	1
229		5.083	5.084	-1	5.085	5.089	-4
228		5.018	5.019	-1	5.024	5.036	-12
227.01	O. B.	5.001	5.005	-4	5.001	5.002	-1
226.01		5.000	5.002	-2	4.999	5.002	-3
225.01		5.000	5.000	0	4.999	4.999	0
224.01		5.000	5.005	-5	4.999	4.999	0
223.01		5.000	4.999	1	4.999	4.999	0
222.01		5.000	5.000	0	4.999	5.000	-1
221.01		5.000	4.999	1	4.999	5.001	-2
220.01		5.000	5.003	-3	4.999	4.999	0
219.01		5.000	5.001	-1	4.999	5.001	-2
218.01		5.000	5.003	-3	4.999	5.001	-2
217.01		5.000	5.000	0	4.999	4.998	1
216.01		5.000	5.005	-5	4.999	4.999	0
215.01		5.001	4.999	2	4.999	4.997	2
210		5.001	4.999	2	4.999	5.002	-3
205		5.001	5.002	-1	4.999	4.997	2
200		5.001	4.999	2	4.999	4.997	2
195		5.001	4.999	2	5.000	4.998	2
190		5.001	5.004	-3	5.000	4.998	2
185		5.001	5.004	-3	5.000	4.999	1
180		5.001	5.002	-1	5.000	5.000	0
175		5.001	5.002	-1	5.000	5.001	-1
170		5.001	5.001	0	5.000	5.001	-1
165		5.001	5.000	1	5.000	5.004	-4
160		5.001	5.001	0	5.000	5.001	-1
155		5.001	5.001	0	5.000	5.001	-1
150		5.001	5.005	-4	5.000	5.000	0
145		5.001	5.004	-3	5.000	5.000	0
140		5.000	5.000	0	5.000	5.000	0
135		5.000	5.000	0	5.000	5.000	0
130		5.000	5.001	-1	5.000	5.000	0
125		5.000	5.002	-2	5.000	5.000	0
120		5.001	5.001	0	5.000	5.001	-1
115		5.001	5.000	1	5.000	5.002	-2
110		5.001	5.001	0	5.000	5.000	0
105		5.000	5.002	-2	5.000	4.998	2

5" 156 No-Lead Propellant Test Stargauge Data

All measurements were on cold gun, with points up.

Distance (in.)		16991 before cop. 7/25/79	16991 156 rds 12/5/94	Diam. Constric x1000	16972 before cop. 2/20/80	16972 156 rds 12/5/94	Diam. Constric x1000
100		5.000	5.004	0	5.000	4.999	1
95		5.000	5.002	-2	5.000	4.998	2
90		5.000	5.003	-3	5.000	5.000	0
85		5.000	5.004	-4	5.000	5.000	0
80		5.000	5.005	-5	5.000	4.998	2
75		5.001	5.005	-4	5.000	5.000	0
70		5.001	5.001	0	5.000	4.998	2
65		5.001	5.004	-3	5.000	5.004	-4
60		5.001	5.003	-2	5.000	5.000	0
55		5.001	5.001	0	5.000	5.004	-4
50		5.001	5.003	-2	5.000	5.004	-4
45		5.001	5.002	-1	5.000	5.002	-2
40		5.001	5.002	-1	5.000	5.001	-1
35		5.001	5.001	0	5.000	5.003	-3
30		5.001	5.002	-1	5.001	5.003	-2
25		5.001	5.002	-1	5.001	5.003	-2
20		5.001	5.002	-1	5.001	5.003	-2
15		5.001	5.002	-1	5.001	5.001	0
12		5.001	5.001	0	5.001	5.002	-1
10		5.000	5.001	-1	5.001	4.999	2
5		5.000	5.002	-2	5.000	5.002	-2
1		5.000	5.004	-4	5.000	5.002	-2
M	Muzzle	5.000	5.001	-1	5.000	5.003	-3

Note

Stargaugings of 5 Dec 94 are regaugings of faulty measurements taken on 6 and 28 Sep 94.

Boresearch of 16991 on 9-28-94

131" from muzzle. Copper build up.
35" from muzzle back to case mouth. Light deposit of copper.

Boresearch of 16972 on 9-28-94

Copper deposit at irreg. 156" from muzzle face. Stops at origin of rifling.
Variation in color green.
180". Heavy.

G621B-CMS
24 FEB 95
R05595-2

Subject: Condition of bore of 5"/54 MK 18 MOD 5 Gun Barrel Serial No. 16972 as shown by visual inspection. (This inspection was done to determine copper build-up only)

1. Moderate Copper deposits exist beginning at origin of rifling and ending 102.0" forward of breech face. This condition exist irregularly throughout the rifling and appears to be green in color. At approximately 52.0" forward of breech face this condition changes from moderate to heavy. The heaviest deposits were noted 88.0" forward of breech face and had a variation of color. In this area the lands have brown copper deposits and the grooves have green.

2. Light rust stains exist irregularly throughout the bore.

3. It should be noted that the aforementioned gun and gun serial no. 16991 fired equal numbers of unleaded NACO rounds between inspections. Serial no. 16972 has much more copper deposits but less rust. The copper deposits appear to act as a protective agent from rusting.

Colleen M. Spillman
COLLEEN M. SPILLMAN
NAVSWC, WEAPONS INSPECTION

NOTE: PHOTOGRAPHS WERE TAKEN IN THE FOLLOWING LOCATIONS:

1. ORIGIN OF RIFLING
2. 52.0" FORWARD OF BREECH FACE
3. 88.0" FORWARD OF BREECH FACE

G621B-CMS
24 FEB 95
R05595-1

Subject: Condition of Bore of 5"/54 MK 18 MOD 5 Gun Barrel Serial No. 16991 as shown by visual inspection. (This inspection was done to determine copper build-up only)

1. Light copper deposits exist from 48.0" forward of breech face and end at 78.0" forward of breech face.

2. Numerous moderate rust stains and pitting exist irregularly throughout the entire length of the gun barrel. These rust stains appear to be bright orange in color.

Colleen M. Spillman
COLLEEN M. SPILLMAN
NAVSWC, WEAPONS INSPECTION

NOTE: PHOTOGRAPHS WERE TAKEN AT 48.0" FORWARD OF BREECH FACE IN THE 11:00 BREECH TIME AREA AND 59.5" FORWARD OF BREECH FACE IN THE 12.00 BREECH TIME AREA.

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COMMANDER US ARMY ARMAMENT RESEARCH, DEVELOPMENT & ENGINEERING CTR SMCAR-AEE-BR (D DOWNS) INFORMATION RESEARCH CENTER PICATINNY ARSENAL NJ 07806-5000	1
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VERITAY TECHNOLOGY ATTN E FISHER 4845 MILLERSPORT HIGHWAY EAST AMHERST NY 14501-0305	1
UNITED DEFENSE LP NAVAL SYSTEMS DIVISION ATTN MAX BRADLEY M310 4800 EAST RIVER ROAD MINNEAPOLIS MN 55421-0099	1
DARMENG-N CP2-6-08 CAMPBELL PARK CANBERRA ACT 2600 AUSTRALIA	1

Internal:

102	1
3220	1
6210	5
8510	2
8530	1